Regular Tutorial 1

"Meeting the Demands of Fault-Tolerant Machine Drives for Safety-Critical Applications"

SPEAKER

Thomas Jahns

Grainger Emeritus Professor, University of Wisconsin-Madison, WEMPEC

SPEAKER

Hamid Toliyat

Robert Kennedy'26 Chair Professor, Texas A&M University

SPEAKER

James Swanke

Senior Machine Design Engineer, H3X Technologies Inc.

Rapidly growing interest in safety-critical applications such as electrified aircraft propulsion is making it critical to focus more attention on the development of high-performance machine drives with ultra-low failure rates. The objective of this tutorial is to provide a thorough introduction/review of both the basic concepts and current state-of-the-art of fault-tolerant machine drives (FT-MDs) by highlighting a variety of major technical approaches that are being pursued around the world. The basic nature of the FT-MD topic demands that the machine, power electronics, controls, and their system integration all be addressed as part of this tutorial. The first part of the tutorial will focus on three key requirements for successful FT-MDs: 1) the critical importance of achieving electromagnetic, thermal, and galvanic isolation between all of the motor drive segments to prevent faults from cascading to healthy segments; 2) the importance of rapid repair rates to return the FT-MD to full health as quickly as possible; and 3)the critical importance of suppressing all sources of single-point failures in the FT-MD unit. Markov chain analysis will be used to illustrate/quantify the impact of each of these factors. Comparisons between the fault tolerance characteristics of different types of machines will be discussed, highlighting appealing or challenging for fault-tolerant machine drive applications. Similar attention will be devoted to comparing different types of power electronic inverters, with a particular focus on the differences between baseline voltage-source inverters (VSIs) and new types of current-source inverters (CSIs)that offer some special fault-tolerance features, particularly for permanent magnet synchronous machines. Comparisons of machine drive control architectures for FT-MDs will also be addressed. Other key topics that will be discussed during the tutorial include: a) fault-tolerant machine phase winding configurations, with particular attention to high-phase-number (>3) windings; b)fault-tolerant modular machine drive (FT-MMDs) that break the machine drive into multiple independent phase-drive units (often 3-phase drive units) that combine their outputs to drive a single output shaft; and c)a discussion of the major fault types that afflict the machines and power electronics used in FT-MDs; and d)a survey of fault detection techniques that are critical to successful FT-MD implementations. Material presented in the tutorial will be illustrated by examples of fault-tolerant machine drive equipment designed, built, and tested by each of the tutorial presenters. For example, analytical and experimental results from development of a 20 kW 4-module FT-MMD unit at UW-Madison will be used to illustrate key concepts. The tutorial will end with a summary of the current status and promising future directions of FT-MD research, including a discussion of key remaining challenges.

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BIOS

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Dr. Thomas M. Jahns received his PhD in electrical engineering from MIT (USA) in 1978. In 1998, Dr. Jahns joined the faculty at UW-Madison as a Grainger Professor of Power Electronics and Electric Machines, where he served as Co-Director/Director of WEMPEC for 14 years (2007-21). Earlier, he worked at GE Corporate R&D in Niskayuna, NY, for 15 years. Since 2021, Dr. Jahns is continuing to pursue research as a Grainger Emeritus Professor on high-performance, fault-tolerant PM machines, and integrated motor drives using wide-bandgap switches.

Dr. Jahns received the 2005 IEEE Nikola Tesla Technical Field Award and the IAS Outstanding Achievement Award in 2011. He has served both IEEE IAS and PELS as a Distinguished Lecturer. Dr. Jahns is a Past President of PELS and Division II Director. He is a member of the US National Academy of Engineering (2015) and received the 2022 IEEE Medal in Power Engineering. Dr. Jahns has a long history of research and technical contributions related to machine faults and fault-tolerant machine drive configurations dating back nearly 50 years to his PhD thesis on induction machine drives using independent phase-drive units.

Prof. Hamid A. Toliyat is the Robert Kennedy '26 Chair Professor in the Department of Electrical and Computer Engineering at Texas A&M University, where he has served since 1994. He earned his B.S. in Electrical Engineering from Sharif University of Technology in 1982, M.S. from West Virginia University in 1986, and Ph.D. from the University of Wisconsin–Madison in 1991.
Prof. Toliyat is internationally recognized for his contributions to the analysis, design, and fault diagnosis of electrical machines, variable speed drives, and magnetic gear integrated electric machines. His research has garnered over 34,000 citations, with an H-index of 88. He has published over 180 journal papers, 385 conference papers, co-authored 11 books and book chapters, and holds 23 issued or pending US patents. He has mentored more than 120 postdoctoral researchers, graduate students, and research engineers.
He has been recognized with numerous prestigious awards, including the IEEE Nikola Tesla Field Award (2014), Cyril Veinott Award, several Patent and Innovation Awards, and the NASA Space Act Award. He is a Life Fellow of IEEE and a licensed Professional Engineer in the State of Texas. Prof. Toliyat has served as an editor for IEEE Transactions on Energy Conversion, chaired the IEEE-IAS Industrial Power Conversion Systems Department, and was General Chair of the 2005 IEEE International Electric Machines and Drives Conference (IEMDC'05). In 2021, he founded Fluxworks, Inc., a technology startup company.

James Swanke (Member, IEEE) received the B.S., M.S., and Ph.D. degrees in electrical engineering from the University of Wisconsin–Madison, Madison, WI, USA, in 2014, 2019, and 2023. During his graduate studies, he was a Research Assistant with Wisconsin Electric Machines and Power Electronics Consortium (WEMPEC), University of Wisconsin–Madison, with primary research interests in the design of power-dense fault-tolerant electrical machines for aerospace applications. He is currently with H3X Technologies, Denver, CO, USA, continuing to develop high power density electrical machines for aircraft propulsion applications. Dr. Swanke's PhD research was focused on the development of an innovative fault-tolerant modular motor drive (FT-MMD) architecture for safety-critical aerospace applications that included experimental confirmation of key fault tolerance characteristics that demonstrated state-of-the-art performance capabilities. He won a Best Paper award from the 2022 IEEE-AIAA Electric Aircraft Technology Symposium (EATS) for his technical paper analyzing the key requirements of successful fault-tolerant machine drives via Markov chain analysis. Dr. Swanke is an active participant in delivering lectures to industry engineers on a variety of ac machine drive topics as part of the highly-regarded short course program offered by the UW-Madison Interdisciplinary Professional Programs (InterPro) office.